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NEURAL NETWORK MODEL FOR ELECTRIC SUBMERSIBLE PUMP SYSTEM

FIELD OF INVENTION

[0001] The present invention relates to modeling behavior of a characteristic of real-world artificial lift technology and systems, more specifically to modeling the behavior of a characteristic of an oil and water artificial lift pump such as an electrical submersible pump (ESP) and its application.

BACKGROUND OF THE INVENTION

[0002] Prior to implementing a design, especially in a production mode, such as for machinery including motors or pumps used with artificial lift technology and systems, manufacturers often like to test assumptions and engineering decisions about that machine. For some machinery, a testing phase can become expensive and involve prototypes and project scheduling delays. Exhaustive testing, e.g. using multiple scenarios to investigate response of the machine to the scenario, can be prohibitively costly or time consuming or both.

[0003] Newer modeling techniques can often save time and cost, e.g. a model of a wind-tunnel session can often be less costly – and nearly or as accurate – as using an actual wind tunnel. Modeling of behavior, such as neural networks, can adapt to changes in supplied environmental variables and can further be refined using real world data, leading to decreased time to market and decreased time to test a new design. Such modeling has been used and/or suggested for such applications as replacement and/or augmentation of flow performance features in a wind tunnel and other flow modeling applications.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] **Fig. 1** is a schematic diagram of an exemplary system for modeling behavior of electric submersible pump application; and

[0005] **Fig. 2** is a flowchart of an embodiment of a method of modeling behavior of electric submersible pump application; and

[0006] **Fig. 3** is a flowchart of an embodiment of a further method of modeling behavior of electric submersible pump application.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0007] Referring now to **Fig. 1**, system 10 for modeling behavior of electric submersible pump application 1 comprises computer 12, data store 14 operatively in communication with computer 12, training data set 20 comprising data 22 stored in data store 14, source 30 of measured data 23 for electric submersible pump application 1 operatively in communication with computer 12; and neural network model 40 of electric submersible pump application 1.

[0008] Training data set 20 is of data related to one or more behaviors of electric submersible pump application 1. Training data set 20 comprises data representative of an electric submersible pump application. These data may relate to at least one predetermined characteristic of the electric submersible pump application and may further be arranged as a plurality of data sets generated from deterministic model 42 of electric submersible pump application 1 where deterministic model 42 may be obtained using at least one mathematical algorithm or at least one collection of mathematical algorithms based on engineering and physics principles that model one or more desired behaviors of electrical submersible pump application 1.

[0009] Data, such as data from source 30 of measured data 23, may be stored in data store 14 which may be a persistent data store, by way of example and not limitation including a magnetic medium, an optical medium, or an electronic medium.

[0010] Neural network model 40 is resident in computer 12. Neural network model is able to utilize training set 20 and measured data 23 to manipulate a model of submersible electrical pump application 1. In a preferred embodiment, neural network model 40 is an adaptable neural network, and, more typically, self-adaptable.

[0011] Neural network model 40 may comprise a weight matrix, a topology of neural network model 40, a training algorithm, an activation function, or the like, or a combination thereof.

[0012] **In the operation of an exemplary embodiment**, referring now to **Fig. 2**, behavior of a characteristic of electric submersible pump application 1 may be predicted by generating, step 100, a training data set 20 comprising data representative of an electric submersible pump application 1, the data related to at least one predetermined characteristic of the electric submersible pump application 1; establishing, step 110, an initial neural network model 40 model for the electric submersible pump application 1, the neural network model 40 model related to the at least one predetermined characteristic of the electric submersible pump application 1; using, step 120, the training data set 20 by the initial neural network model 40 to create a predictive model of behavior of the at least one predetermined characteristic of the electric submersible pump application 1; obtaining, step 130, measured electrical submersible pump application operational data; and adapting, step 140, the neural network model 40 using the measured electrical submersible pump application operational data 23 to create a predictive

model of behavior of the at least one predetermined characteristic of the electric submersible pump application 1.

[0013] In a preferred embodiment, training data set 20 is generated from deterministic model 42 of an electric submersible pump application 1. Training data set 20 may be obtained from data related to electric submersible pump application 1 as installed and used in a real world environment.

[0014] As will be understood by those of ordinary skill in the neural network arts, weight matrix 45 (not shown in the figures) may be adjusted using training algorithm 46 (not shown in the figures) that corresponds to neural network model 40 to predict actual behavior of electric submersible pump application 1 such as by minimizing a training error.

[0015] A predetermined output of neural network model 40 may be used to aid with data matching of historical measured data versus the output, fault diagnosis of electric submersible pump application 1, prediction of an operational characteristic of the electric submersible pump application 1, or the like, or a combination thereof.

[0016] Adaptation of neural network model 40 may be self-adaptation.

[0017] In a further embodiment, referring now to **Fig. 3**, modeling may occur in stages, e.g. a learning stage may be provided, step 200, a testing stage may be provided, step 210, and an adaptive stage may be provided, step 220.

[0018] The learning stage may comprise modeling one or more desired behaviors of electric submersible pump application 1 such as by using one or more deterministic mathematical algorithms based on engineering and physics principles that model the desired behavior of electrical submersible pump application 1. Training data set 20, comprising of data related to the desired behavior of electric submersible pump application 1, may be generated

from the modeled behavior. Once generated, training data set 20 may be provided to an initial neural network model 40 and neural network model 40 created to model one or more predetermined characteristics of electric submersible pump application 1.

[0019] The behavior model of electric submersible pump application 1 may be dependent on a predetermined number of inputs and outputs related to behavior of an actual electric submersible pump application 1. Such a behavior model may be useful for a prediction of a desired behavior of an actual electric submersible pump application 1, adaptation of a desired behavior of an actual electric submersible pump application 1, or the like, or a combination thereof.

[0020] During a testing stage, a measured data set 23 may be obtained for the electric submersible pump application 1. At least one output from neural network model 40 may be generated where the output relates to the one or more predetermined characteristics of the electric submersible pump application 1, e.g. for validation purposes. The output from neural network model 40 may comprise a simulated value for the predetermined characteristic of the electric submersible pump application 1, a calculated value for determined characteristic of the electric submersible pump application 1, or the like, or a combination thereof.

[0021] One or more predetermined outputs of the behavior model of the neural network model 40 may be compared to real world data for a desired behavior modeled by the neural network model 40. Further, during an adaptive stage, revisions of neural network model 40 may be iterated, e.g. by self adaptation of neural network model 40, to refine obtained predicted electric submersible pump application 1 behaviors, e.g. by the comparison process described above.

[0022] For example, once compared, further analysis may be undertaken, e.g. neural network model 40 may be adapted, either by neural network model 40 itself or by another process or by human intervention. In a further embodiment, neural network model 40 may be used to provide automated interpretation of real world data related to electric submersible pump application 1. By way of additional example, real world data related to actual behavior of electric submersible pump application 1 may be obtained, e.g. from source __ and then provided to neural network model 40. These real world data may be used during iterations of neural network model 40 to improve predictions of behavior.

[0023] It will be understood that various changes in the details, materials, and arrangements of the parts which have been described and illustrated above in order to explain the nature of this invention may be made by those skilled in the art without departing from the principle and scope of the invention as recited in the appended claims.